Journal of Forensic and Legal Medicine 19 (2012) 126–131

Contents lists available at SciVerse ScienceDirect

Journal of Forensic and Legal Medicine

journal homepage: www.elsevier.com/locate/jflm

Original communication

CT based volume measurement and estimation in cases of pericardial effusion

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ARTICLE INFO

Article history:
Received 5 August 2011
Received in revised form
24 October 2011
Accepted 12 December 2011
Available online 15 January 2012

Keywords:
Virtopsy
Post-mortem CT
Segmentation
Cardiac effusion
Volume estimation

ABSTRACT

The measurement of fluid volumes in cases of pericardial effusion is a necessary procedure during autopsy. With the increased use of virtual autopsy methods in forensics, the need for a quick volume measurement method on computed tomography (CT) data arises, especially since methods such as CT angiography can potentially alter the fluid content in the pericardium.

We retrospectively selected 15 cases with hemopericardium, which underwent post-mortem imaging and autopsy. Based on CT data, the pericardial blood volume was estimated using segmentation techniques and downsampling of CT datasets. Additionally, a variety of measures (distances, areas and 3D approximations of the effusion) were examined to find a quick and easy way of estimating the effusion volume.

Segmentation of CT images as shown in the present study is a feasible method to measure the pericardial fluid amount accurately. Downsampling of a dataset significantly increases the speed of segmentation without losing too much accuracy. Some of the other methods examined might be used to quickly estimate the severity of the effusion volumes.

1. Introduction

Pericardial tamponade is in most cases caused by natural diseases such as ruptured myocardial infarction or ruptured dissecting aneurysm of the aorta and often leads to sudden and unexpected death.[1] Furthermore, blunt or penetrating trauma to the chest can induce pericardial tamponade.[1,2] According to the literature, only 6% of patients with traumatic pericardial tamponade reach the hospital alive.[2] Cardiac tamponade cannot be diagnosed by external examination alone and autopsy is required to investigate the cause of death. As little as 100 ml of fluid (compared to 15–50 ml of pericardial fluid normally) in the pericardial sac can be fatal depending on how rapidly the fluid accumulates.[3] In general, 400–500 ml is thought to be sufficient to cause death even though smaller volumes are often seen in fatal pericardial tamponades.[1]

In clinical settings, ultrasound is the imaging technique of choice for diagnosis of pericardial effusions, since it is usually available, quick, highly sensitive and comes without patient exposure to ionizing radiation.[4] Although ultrasound is very specific for diagnosis of pericardial tamponade,[4] attempts of measuring the volume by measuring the distance between myocardium and pericardium cannot deliver accurate volume measurements because the entire effusion cannot be visualized with ultrasound.[5] In forensic pathology, attempts have been made to use ultrasound for diagnosis of pericardial tamponade at external examination but difficulties arise when the heart is overlapped by the left lung or if gas from decomposition is present.[6] Furthermore ultrasound can only rarely determine the cause of pericardial tamponade.[6]

Another image modality used in clinics to diagnose pericardial tamponade is computed tomography (CT). The main advantage compared to ultrasound is a larger field of view, which allows identification of associated pathologies and injuries in the chest as cause of pericardial tamponade. Since CT scanning is less operator dependent, it has a lower rate of false-positive findings than echocardiography.[2]

The severity of pericardial tamponade is important in clinical settings as well as in forensic pathology to decide whether a life-threatening situation is present or if death occurred from pericardial tamponade. With the increased use of virtual autopsy methods, a technique to estimate pericardial effusion volumes is desirable.[7]

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1752-928X/$ – see front matter
doi:10.1016/j.jflm.2011.12.007

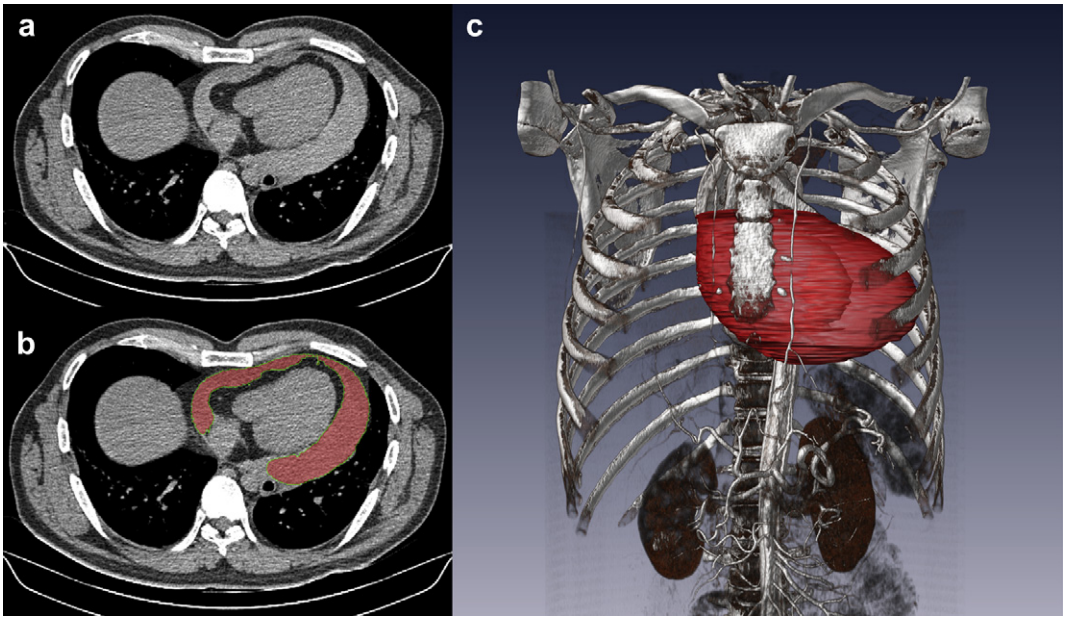

Fig. 1. Volume measurement by segmentation using axial CT images (a). A: Pericardial effusion is marked manually for each slice or resampled slices.(b). C.: 3D reconstruction of segmented pericardial effusion.

The aim of the present study was the development of a non-invasive method to determine the volume of pericardial tamponade in postmortem CT (pmCT). We assesed two methods to achieve this goal: First, the time-consuming but more accurate method of manual segmentation of the pericardial fluid in every axial CT image. Second, an alternative segmentation method that uses downsampled datasets and therefore is probably less accurate but much faster. The results of both methods were validated by comparing post-mortem CT volume measurements with autopsy findings. Additionally, the accuracy of segmentation was validated on a phantom.

2. Materials and methods

2.1. Case selection and autopsy results

Retrospectively, we selected 15 post-mortem cases that underwent pmCT prior to forensic autopsy and in which more than 50 ml of liquid were measured in the pericardial sac during autopsy.

The average age of the decedents was 46 years (±20.5,median 48 years), ten were male and four female. We excluded cases with signs of advanced decomposition and extensive damage to the heart as well as ruptures of the pericardial sac. Cases included natural and unnatural deaths. In eight cases, lethal trauma had occurred. In six cases a cardiac tamponade caused by rupture after myocardial infarction or aortic aneurysm lead to death. One person died of sepsis. The mean interval between estimated times of death and imaging was 21.4 h, ranging from 4.5 to 70 h. A standard forensic autopsy was performed in all cases. The pericardial sac was opened by a lambda incision. The fluid was collected and the volume estimated in a measuring cup.

In six out of our 15 cases, a postmortem CT angiography (pmCTA)[7] was performed. In one of those six cases, contrast agent was present in the pericardial sac.

2.2. Postmortem computed tomography (pmCT) scanning

Scanning was performed on a Siemens Somatom Emotion 6 (Siemens, Germany). All corpses underwent full body PMCT

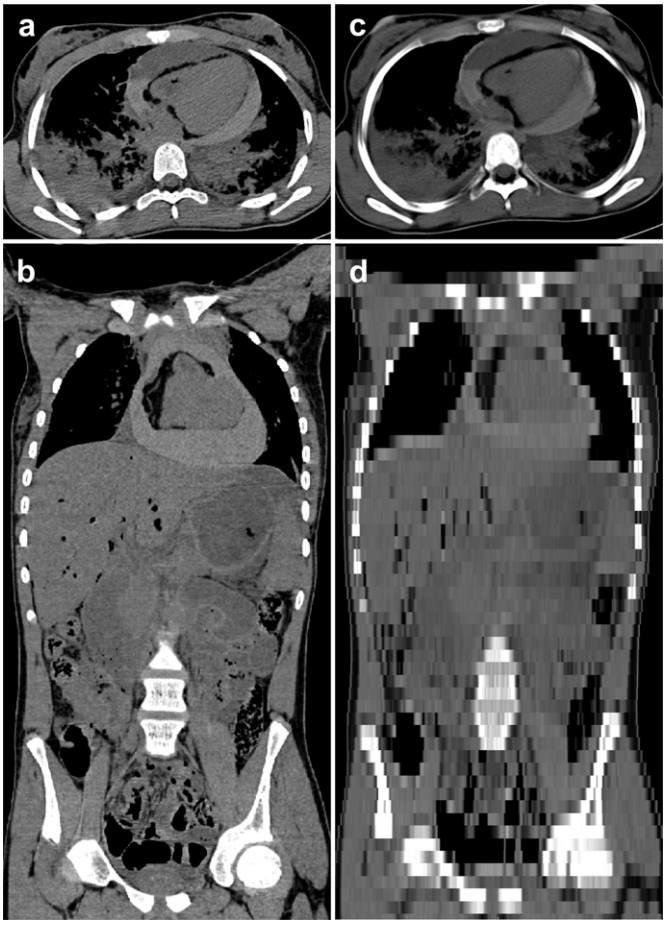

Fig. 2. Standard CT dataset with axial (a) and coronal (b) views on the left, downsampled dataset with axial (c) and coronal (d) views on the right. Since the resampling is only performed in direction of the slices, the main loss of quality is visible in the coronal view. The appearance of the axial cuts is slightly altered, but the effusion can still clearly be seen and easily segmented. The number of slices in which the segmentation is performed is significantly decreased, therefore saving considerable time.

imaging in supine position including a thorax scan with elevated arms for better image quality of the thorax region. Raw data acquisition was performed with the following settings: 130 kV; 95.8–230 mA (case dependent); collimation 6 × 1 mm. Image reconstruction was carried out in 1.25 mm slice thickness in soft tissue reconstruction kernel. For pmCTA, a mixture of polyethylene glycol and iopentol was applied.[8] Primary image review was performed on a workstation using Osririx (Osirix foundation, Switzerland) software.

2.3. Segmentation and volume calculation

Segmentation is a technique that assigns a material property to every picture element – in case of CT data to every volume pixel (voxel). Different algorithms and procedures exist to accomplish this, depending on the image modality and the structure that should be segmented. Since the pericardial blood has a similar Hounsfield value to surrounding tissue such as liver, we segmented the data with a combination of thresholded masking and manual selection of the liquid filled pericardium using the Amira software package (VisageImaging, Germany) (Fig. 1). For masking, the threshold selected was case specific and defined in a way that allowed the operator to select intrapericardial fluids as well as myocardium. A thin layer of epicardial fat allowed the operator to distinguish between these two and manually segment the intrapericardial fluid. Mediastinal vessels were either not visible (collapsed) or if visible, not included in the segmentation. Finally, the volume was calculated automatically by counting the number of voxels selected and multiplying them with the volume of each voxel.

Blood in the pericardial sac was segmented for each case. The segmentation was performed by a forensic pathologist and validated by a board certified radiologist. Both were blinded to the volume measurements obtained at autopsy. In order to speed up the segmentation process, we additionally resampled all datasets using Amira to a slice thickness of 10 mm (Fig. 2).

2.4. Segmentation accuracy

Even though segmentation techniques have been used for volume estimation,[9] we performed an accuracy test on a phantom. A plastic vessel was filled with water using a syringe. CT scans were performed with following parameters: 130 kV, 100 mA, 6 × 1 mm collimation and 1.25 mm slice thickness. The volume was measured by segmentation without resampling. This was repeated for volumes from 25 ml to 575 ml in steps of 25 ml. Finally, we calculated the correlation, mean, median and standard deviation.

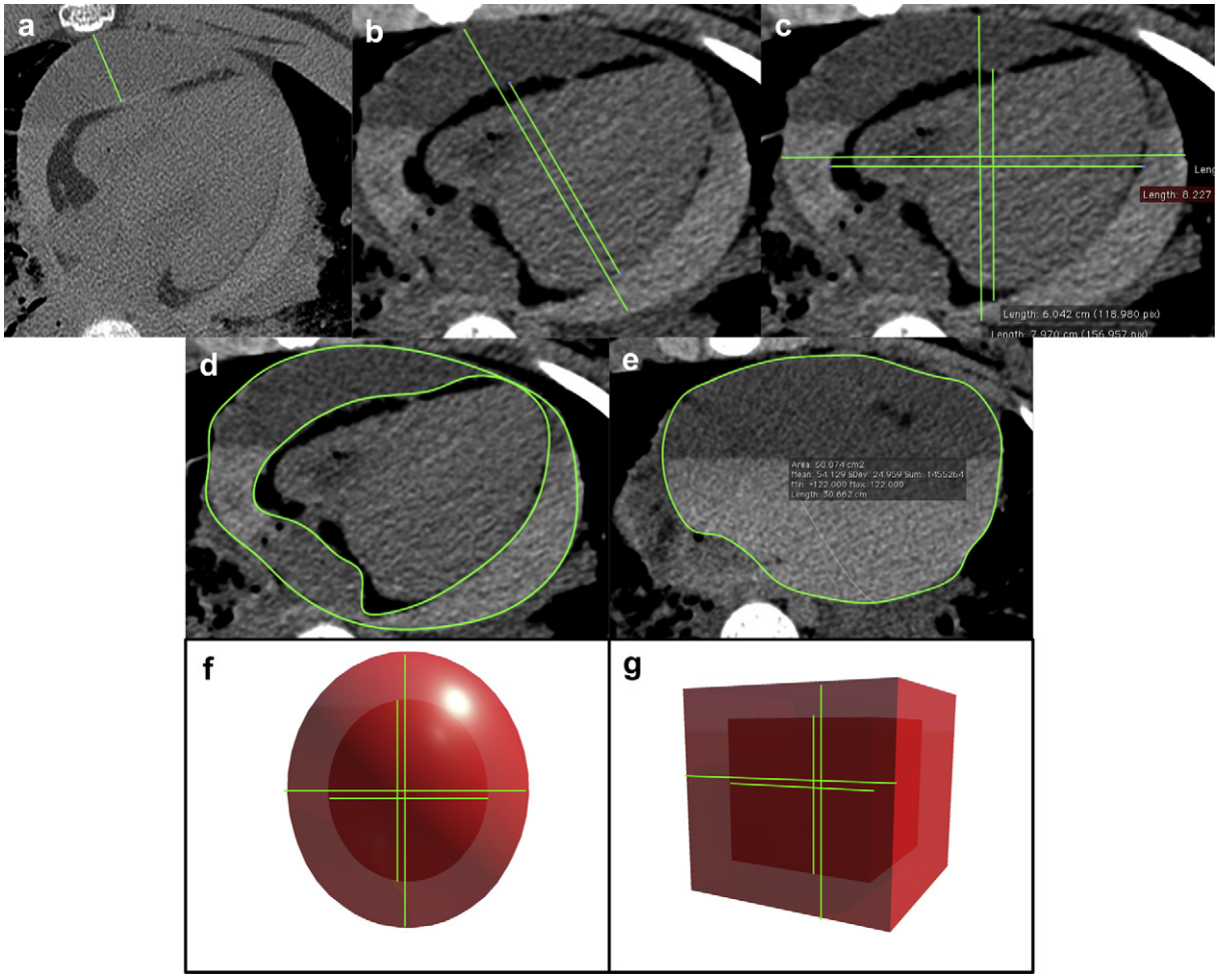

Fig. 3. Different methods for estimating the effusion volume in the pericardial space. a: Greatest thickness of effusion in region subjacent to the sternum (Effusion).b: The diameter of pericardial effusion minus the heart diameter measured along the same path as the measurement in a.(Effusion double) c: Same axial level as a and bin true anteroposterior and transverse directions, measurement of pericardiam diameter minus heart diameter (Effusion two axes). d: Same axial level as a, b and c: Circumferential area of pericardium minus circumferential area of the heart (Effusion surface). e:Circumferential area of effusion at the tip of the left ventricle (Effusion left ventr.). f: Volume estimation with an ellipsoid, based on measurements in c (Elliposoid). g: Volume estimation with a cube, based on measurements in c (Cube).

2.5. Volume estimation in CT

In order to find a quick way of estimating the volume of pericardial fluids, we measured different distances and areas and correlated them with the volume estimated by segmentation. The following measures were taken (Fig. 3):

One dimensional measurements:

a) Greatest thickness of effusion in region subjacent to the sternum.
b) The diameter of the pericardial effusion minus the heart diameter measured along the same path as the measurement in a.
c) Same axial level as a and b, in true anteroposterior and transverse directions, measurement of pericardiam diameter minus heart diameter.

Two dimensional measurements:

d) Same axial level as a, b and c: Circumferential area of pericardium minus circumferential area of the heart.
e) Circumferential area of effusion at the tip of the left ventricle..

Three dimensional measurements:

f) Volume estimation with an ellipsoid (based on measurements in c).
g) Volume estimation with a cube (based on measurements in c).

To find the best measure, we correlated the results of these measurements with the segmented volume using Pearson's correlation coefficient. Normal distribution was tested with the Kolmogorov–Smirnov test. Finally, the measurements were compared to each other by using a paired *t*-test. For statistics, we used SPSS (SPSS Inc, Chicago, USA) and Excel (Microsoft Corp., Redmond, USA).

3. Results

3.1. Accuracy of cardiac effusion volume measurement using segmentation

The accuracy validation with the water phantoms shows a mean error of 11.3 ml (±6.8, median = 12 ml, $n = 23$) (Fig. 4). On average, 335 ml (±199 ml) were measured in the pericardium during autopsy, for volume estimation by segmentation 393 ml (±204 ml) and for volume estimation on resampled datasets 372 ml (±189 ml) (Fig. 5). The Kolmogorov–Smirnov-Test showed a normal distribution for all three datasets. The paired samples *t*-test between autopsy and segmentation showed a significant difference between both measurements techniques ($t = 2.468$, df = 13, $p = 0.009 < 0.05$). The same was the case when comparing autopsy results to resampled segmentation data ($t = 0.963$, df = 13, $p = 0.034 < 0.05$). The paired samples *t*-test showed no significant difference between standard segmentation and segmentation on resampled datasets ($t = 2.243$, df = 13, $p = 0.108$). Segmenting one dataset took between 30 min and 1 h, depending on the size of the heart and the slice thickness of the CT dataset. The time required for segmentation of a downsampled dataset was 2–5 min.

The results of the correlation of different measurements with the volumes measured by segmentation can be seen in Table 1. All correlations are significant. The correlations of the three-dimensional approximation methods however have the highest correlation value with 0.66 ($p = 0.002 < 0.01$).

4. Discussion

We used segmentation techniques to assess the liquid volume of pericardial blood. The quality of the segmentation depends on the ability to distinguish liquid from surrounding soft tissue. In cases of hemopericardium, blood in the pericardium can be

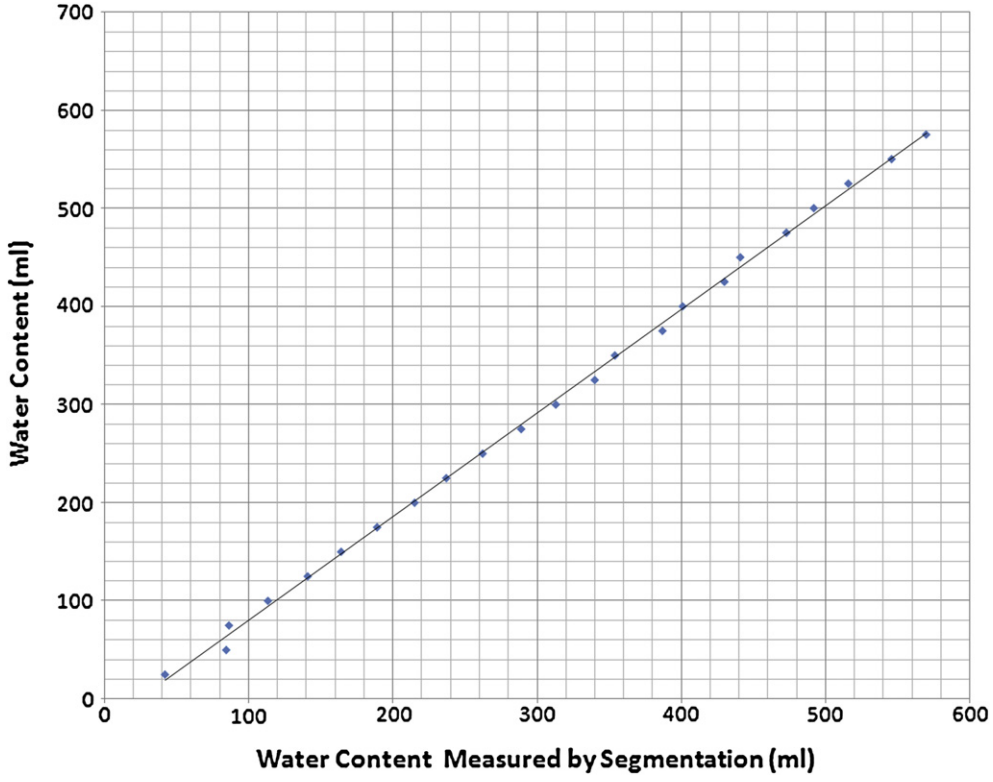

Fig. 4. Water phantom – comparing segmented water volumes to the actual amount of water.

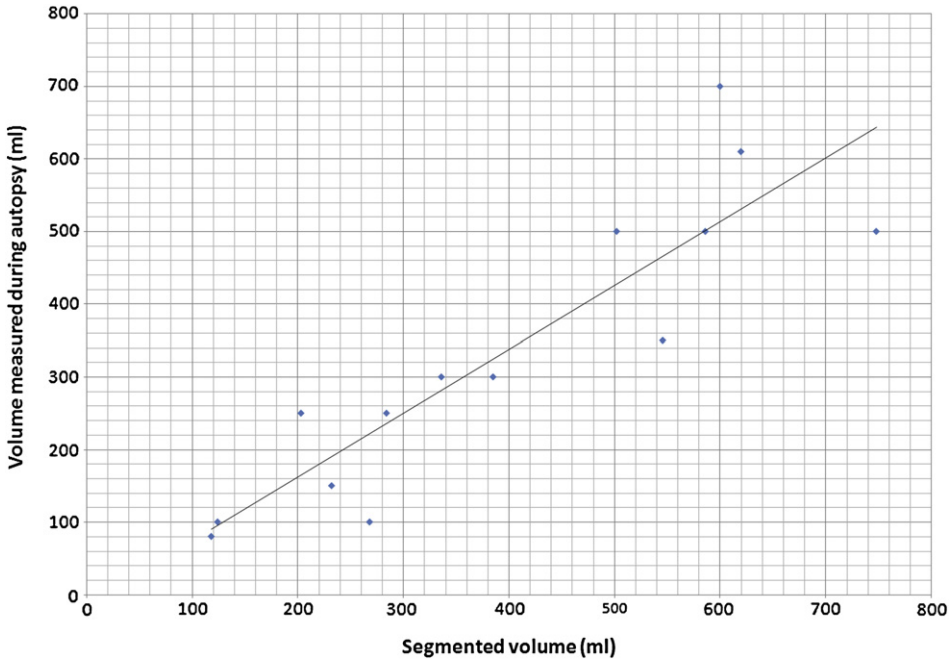

Fig. 5. Comparing segmented pericardial effusion volumes to volumes measured during autopsy.

easily identified and distinguished from lung and liver tissue, which makes segmentation a good tool for estimating volumes in these cases. This technique is also applicable to other pericardial effusions and may be even easier to perform with low-density fluid collections.

Comparing autopsy measurements of pericardial liquids with our segmentation based measurements shows significantly different results. On average, the volume measured during autopsy is lower than the volume estimated by segmentation. This can be explained by the manner in which the autopsy measurements are performed. For cases with large amounts of blood in the pericardium, an incision in the pericardial sac can lead to leakage of fluid. Additionally, clotted blood is sometimes not entirely removed. This is supported by the fact that, especially for larger volumes, the autopsy measurements tend to be smaller than the estimation by segmentation. The present study was retrospective so that special regard to fluid measurement during autopsy was not possible. There are substantial inaccuracies in routine autopsy measurements due to collecting, measuring and rounding errors. At autopsy, volumes are often rounded to 50 ml values. Cases with 500 ml or more pericardial fluid may be rounded to the nearest 100 ml. In view of the fact that volume estimation using segmentation is based on CT data, the pericardial effusion is relatively easy to identify and the accuracy of fluid segmentation was validated in our phantom experiment, we propose, that the segmentation procedure is as accurate as autopsy measurements.

Table 1
Correlation of different measures with the volume measured by segmentation, *P*-value and Kolmogorov–Smirnov test for normal distribution. A) a.: Greatest thickness of effusion in region subjacent to the sternum. b.: The diameter of pericardial effusion minus the heart diameter measured along the same path as the measurement in a. c.:Same axial level as a and bin true anteroposterior and transverse directions, measurement of pericardiam diameter minus heart diameter.d.: Same axial level as a, b and c: Circumferential area of pericardium minus circumferential area of the heart. e.:Circumferential area of effusion at the tip of the left ventricle.f.: Volume estimation with an ellipsoid (based on measurements in c). g.:Volume estimation with a cube (based on measurements in c).

	Correlation	*P*-Value	KS test P
a	0.593972959	0.013	0.74
b	0.628988888	0.009	0.54
c	0.59977936	0.005	0.52
d	0.471781603	0.02	0.52
e	0.563368225	0.009	0.35
f	0.658182311	0.002	0.99
g	0.658182311	0.002	0.99

Since the segmentation process is time-consuming for high-resolution datasets, we also segmented in downsampled datasets. This allowed us to significantly speed up the segmentation process, without sacrificing too much accuracy. With this technique, the severity of a pericardial effusion can be quickly quantified without opening the body. In addition, this might be a method useful in clinical settings, especially in non-acute life threatening cases to determine if needle pericardiocentesis is indicated.

Additionally, we correlated different measures of the heart and pericardium to find a quick and simple way to estimate the effusion volume in the pericardium. We chose one-dimensional measures such as the thickness of the pericardial effusion, two-dimensional measures, such as the area of the filled pericardium and the three-dimensional approximation with ellipsoids and cubes. The three-dimensional volume estimation methods correlate better with the actual volume than the two-dimensional measures. This can be explained by a non-linear dependency of the one- and two-dimensional methods to the actual volume, which leads to a lower correlation coefficient. Three-dimensional methods can be used to quickly estimate the volume, but are less accurate than segmentation and not necessarily faster than segmentation using downsampled datasets. One dimensional methods such as the one in Fig. 3a, though not very accurate, do not require special hard –or software, are easy to perform and very time efficient. They could be used to quickly assess the severity of an effusion.

In forensic cases, where a pmCTA for detection of pathologies or injuries of the vessels is performed, the amount of liquid in the pericardium and therefore the autopsy measurements of pericardial tamponade can be altered. By performing a native pmCT prior to the pmCTA and using segmentation techniques, the effusion volume in the pericardium can still be accurately determined.

Since gas can easily be detected in pmCT, segmentation techniques can also be used for estimating gas volumes.[10] This would allow for an otherwise difficult measurement of intrapericardial gas volumes.

5. Conclusion

Manual segmentation of every slice gained from axial CT images as shown in the present study is a feasible method to measure the pericardial fluid amount accurately. Based on the highly accurate phantom validation and the weakness of traditional measurements at autopsy, we propose segmentation techniques for effusion measurement in cases where autopsy measurements are problematic. Our 2D and 3D methods may allow for a quick estimation of the severity of pericardial effusions on pmCT. Segmentation techniques in combination with downsampling of the dataset offer a slightly slower, easy, non-invasive and accurate way of determining the effusion volume. This allows for the determination of pericardial volumes, prior to pmCTA.

Conflict of interest

The authors declared there is no conflict of interest.

Funding

None declared.

Ethical approval

The responsible local justice department and the ethics committee of the university both approved this study.

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